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ASSESSING THE VALIDITY OF THE RIDE MOTION SIMULATOR FOR A REMOTE VEHICLE CONTROL TASK

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The lightweight, fast-moving design proposed for operations occurring within 5-10 years requires Soldiers riding as passengers in moving vehicles to perform operations previously conducted only in stationary environments. Operating under motion conditions can lead to performance degradations associated with physical perturbations and conflicting sensory inputs, which are associated with motion sickness. Full-motion simulators offer the flexibility to model and rapidly test multiple vehicle profiles and crew station design configurations while providing increased experimental control. However, a major concern is whether or not a simulator can evoke the behavioral responses observed in real life. This validation study compares the results of two complementary experiments that examined task performance while operators underwent either simulated or actual vehicle motion. Driving performance indicated differences between the experiments for several measures, while motion sickness questionnaire subscales indicated similar patterns of results across both experiments. Overall, support was found for both *absolute* and *relative* validity of using the simulator to examine issues related to motion sickness, but not for performance measures. Our results support the premise that simulators can be valuable for inducing specific types of real-life behaviors that will be inherent to designs proposed for future forces.

INTRODUCTION

The lightweight, fast-moving design proposed for future forces requires Soldiers riding in moving vehicle to perform operations that were previously conducted only in stationary environments. Operating under motion conditions can lead to performance degradations associated with physical perturbations, sensory inputs, and central nervous system functioning. Furthermore, operating in an enclosed moving environment creates a situation defined by potential sensory mismatch, which can contribute to cognitive and physical performance degradation and motion sickness (Reason & Brand, 1975).

Motion-base simulators have the potential to safely, rapidly, and cost-effectively test Soldier performance using multiple vehicle motion profiles and crew station design configurations, while providing increased experimental control (Reed & Green, 1999). A major concern is if motion simulators can provide reasonable approximations of the ride characteristics experienced by crewmembers for the purposes of evoking the behavioral responses observed in real life, i.e., the behavioral validity of the simulator (Blaauw, 1982).

Validation

Validity can be considered as either *absolute* or *relative* (Blaauw, 1982). A simulator is said to have *absolute validity* if human-vehicle system performance observed within the simulator is of the same *scale* as that observed in real life. A simulator is said to have *relative validity* if the same *trend* for a given task is seen within the simulator and in real life.

Validity is also task specific (Blaauw, 1982). Future forces will perform control tasks such as vehicle

teleoperation while "on the move". Adding motion cues through the use of a motion-base is generally believed to increase performance in vehicle control type tasks (McLane & Wierwille, 1975; Reed et al., 1999). However, previous research has focused on motion cues that represent the motion of the controlled vehicle. By contrast, a major concern to future force development is the situation in which the operator experiences cues that do not match that of the controlled vehicle. This occurs when a crewmember operates a remote vehicle while seated in another moving vehicle. Motion-base simulators can be used to simulate such a scenario in more controlled laboratory conditions. However, due to the inability to perfectly re-create vehicle motions, a validation of this scenario was performed which focuses on comparing the influences of simulated physical vehicle motion on task performance to that of actual physical vehicle motion.

Purpose

The objective of the study reported in this paper is to examine the validity of the Ride Motion Simulator (RMS) (see details in the Method section) as a tool to examine human performance issues within the Soldier environment expected for the future forces. The specific purpose was to establish validity for the situation in which a crewmember teleoperates or "drives" a remote unmanned vehicle while seated in another moving vehicle. This situation is marked by the differences between the operator's own self-motion and the visual motion the operator observes via an indirect vision system.

These differences are expected to lead to performance decrements in driving behavior and incidences of motion sickness. This study, which focuses on the High Mobility

Multi-Purpose Wheeled Vehicle (HMMWV), is part of a program of research, the purpose of which is to establish the behavioral validity of the RMS for simulating vehicle motion for both performance and motion sickness measures.

The study was conducted to address the following research questions:

- How accurately does teleoperator performance in the RMS resemble that of a teleoperator in a real combat vehicle?
- How similar are the reports of motion sickness in the RMS environment to that of a real combat environment?

METHOD

The results of two complementary experiments studying a vehicle control type task within a simulated HMMWV and an actual HMMWV were compared. The first experiment (Simulator Experiment) focused on performance differences between simulated indirect driving and simulated vehicle teleoperation under several conditions. The second experiment (Vehicle Experiment) examined the effects of different physical motion environments on an operator of a simulated remote vehicle. As detailed below, both experiments followed the same general protocol and two of the four conditions in each experiment were identical with the exception of the use of the RMS to simulate the HMMWV motion (Simulator Experiment) versus the use of an actual HMMWV in the field (Vehicle Experiment).

Participants

The participants ($n = 16$ per experiment) for the validation study were male and female volunteers drawn from soldiers at Detroit Arsenal, and employees from the workforces at TARDEC and DCS Corporation (Simulator Experiment), and the U.S. Army Research Laboratory – Human Research and Engineering Directorate (ARL-HRED) and DCS Corporation (Vehicle Experiment). The voluntary, fully informed consent of the persons used in this research was obtained as required by 32 CFR 219 and AR 70-25 (Code of Federal Regulations, 1999). The investigators adhered to the policies for the protection of human subjects as prescribed in AR 70-25 (Department of the Army, 1990). Employees who participated did not receive any compensation other than their regular pay. Overall, 8 participants ($n = 5$ Simulator; $n = 3$ Vehicle) had experience driving HMMWV's (7.0 ± 1.7 yrs (s.e.)). Attempts were made to match the participants for age (29 ± 2.3 Simulator; 31 ± 2.0 Vehicle), occupation ($n = 4$ military per experiment), and gender (female participants: $n = 4$ Simulator; $n = 3$ Vehicle).

Experimental Design

In both experiments, participants completed an identical task in four conditions. The task consisted of participants driving a physics-based HMMWV model over a digitized version of the Ground Vehicle Experimentation Course (GVEC) located at Aberdeen Proving Ground (see Figure 1). The primary manipulation in both experiments was the type

of physical motion. In both experiments, participants completed the driving task while undergoing conditions in which the vehicle they rode either idled (Idling) or moved in a manner not linked with the remote driving task (Moving). These two conditions, completed in both experiments, were assessed as the basis for this validation. In the Simulator Experiment, the remaining two conditions involved a manipulation of the relationship of task performance to the physical motion. In the Vehicle Experiment, the influences of physical oscillations on task performance were examined in the remaining two conditions. The order in which the participants experienced the driving conditions within each experiment was counterbalanced and subjects were randomly assigned across conditions and orders.

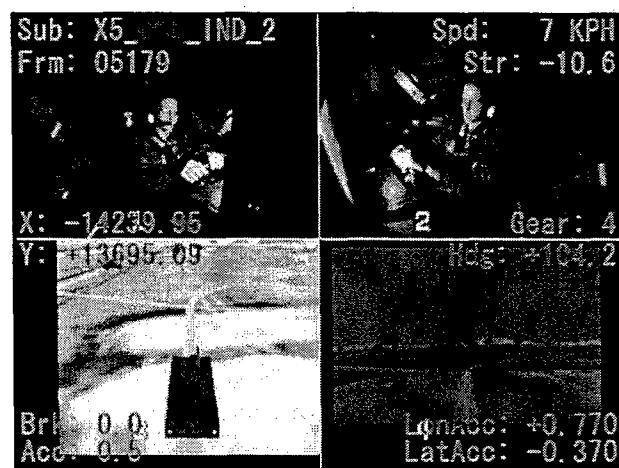


Figure 1. Experimental Setup. The upper quadrants show a participant in the replicated HMMWV control stations. The lower left quadrant is a bird's-eye view of the controlled vehicle, which is following the yellow path. The lower right quadrant illustrates the participant's view during the task. In both lower views obstacles can be seen in the distance.

Apparatus and Equipment

The station for the remote vehicle control task included 1) an 18-inch active matrix LCD flat panel display (1280 X 1024 pixel resolution, 170° viewing cone, 235 nit brightness, 350:1 contrast ratio, and 25 ms typical pixel response time), 2) a steering wheel, and 3) an accelerator and brake pedal assembly located at the participant's feet. The control task used the SimCreator® Software package (Realtime Technologies, Inc., Royal Oak, MI), which simulated the vehicle dynamics and displayed an approximately 40° horizontal x 30° vertical field-of-view computer generated color image of the forward terrain. The simulated camera was located along the centerline of the HMMWV, at roof height above the windshield. As the visual portions of the vehicle control task were not manipulated in this experiment, only the general details of the visual simulator are specified.

The vehicle teleoperation station was located in either a replication of a HMMWV right rear passenger side seat (see Figure 1) or an actual HMMWV seat. In the Simulator Experiment, the station replicated the size, location, and

orientation of the seat, steering wheel, foot-pedals, and visual display located within an enclosed cab. The cab was mounted on top of the RMS (MTS Systems) (<http://www.tacom.army.mil/tardec/nac/teams/mbt/rms.htm>) located at the Ground Vehicle Simulation Laboratory (GVSL) at the US Army Tank and Automotive Research, Development and Engineering Center (TARDEC). The RMS, which generated the simulated motion, is a 6 degree-of-freedom (DOF) motion-base that is capable of simulating the ride dynamics and characteristics of a wide range of military ground vehicles traversing a vast array of ground surfaces to include secondary roads and cross country terrain. The platform supports a reconfigurable cab that is large enough to allow the examination of crew station designs.

In both experiments, the physical vehicle motion experienced, either simulated or actual, was generated from the vehicle traversing the GVEC. The data presented in Table 1 show the differences in the motion profile of the Moving Condition between experiments. The crest factor (C.F.), the ratio of the peak amplitude to the root mean squared error value, describes the amount of distortion in a fluctuating signal. The differences observed in the motion profiles between the Simulator and Vehicle are consistent with expectations due to the inherent characteristics of RMS simulation of HMMWV motion dynamics.

Table 1. Ride Quality. Root mean square errors (RMSE) and crest factors (C.F) for angular (deg/s^2) and linear (m/s^2) accelerations for each experiment.

	Simulator		Vehicle	
	RMSE	C.F.	RMSE	C.F.
Pitch	37.2	11.4	5.7	13.2
Roll	33.5	10.5	4.8	9.0
Yaw	17.8	8.0	n/a	n/a
Vertical	1.4	3.5	1.3	5.6
Translation	0.7	14.1	1.2	1.8
Longitudinal	0.7	7.2	1.1	7.4

Demographic, medical and experience data were used as a screening tool in addition to providing descriptive data. An auditory version of the Motion Sickness Assessment Questionnaire (MSAQ) (Gianaros, Muth, Mordkoff, Levine, & Stern, 2001) was used for the subjective estimation of motion sickness. A physical discomfort questionnaire, adapted from the Loudon Burn Chart (see Wilson & Corlett, 1990), was used to monitor participant state for safety reasons but was not analyzed. Postural sway and cognitive tests were also administered; however, they fall outside the scope of this paper and are not discussed further.

Driving Task

The driving simulation course was a digitized version of the GVEC test area in daylight conditions (see Figure 1). The course, which consisted of dirt- and gravel-colored road segments and grass covered cross-country terrain, followed a serpentine route covering approximately 1.5 miles. A six inch wide yellow stripe marked the centerline of the entire

course. During the test conditions, five HMMWVs were placed on the course as obstacles that must be driven around to increase the task difficulty and novelty. The locations of the obstacles were randomized across conditions. Striking an obstacle did not influence the motion of the platform; however, the participant was informed when a collision occurred. Participants were instructed, "Drive as quickly as possible while keeping the center of the vehicle on the yellow line. Do not in any circumstance hit another vehicle."

Procedure

A similar procedure was used to conduct both experiments. Prior to the start of the experiment, participants were briefed and provided informed consent. They completed training and baseline measurements on the questionnaires and were familiarized with the simulators. The participants then completed the test conditions each of which consisted of four 10-minute driving trials. After each trial, the participants completed the MSAQ. After the last trial, the participants exited the testbed, completed the exit interview, were debriefed, and released when they were free of motion sickness symptoms.

Data Reduction

For the driving task, dependent measures based on speed and accuracy of lateral position were derived from the database coordinates. The course was first segmented into sections of like-radius. For each segment that was obstacle-free, average speed (Speed) and the average lateral deviation (Error) were computed. Error was computed as the root mean square of the position of the vehicle subtracted from the coordinates of the centerline of the test track on a nearest-neighbor, point-by-point basis. For both Speed and Error, exponential curves were fit relating the measure to the curve radius (Emmerson, 1970). This method resulted in coefficients representing the maximum speed ($\text{Speed}_{\text{MAX}}$) or minimum lateral deviation ($\text{Error}_{\text{MIN}}$) and how the speed or the error changed as a function of the path radius (Speed_{CC} , Error_{CC}).

The percentage of errors (% Error) was computed as the number of times a participant either contacted an obstacle or got lost while avoiding an obstacle divided by the total number of obstacles passed.

The four subscales of the MSAQ were examined in accord with recommendations by Gianaros et al. (2001). The four subscales include Gastrointestinal (sick to stomach, queasy, nauseated, may vomit), Central (faint-like, lightheaded, disoriented, dizzy, spinning), Peripheral (sweaty, clammy/cold sweat, hot/warm), and Sopite-Related (annoyed/irritated, drowsy, tired/fatigued, uneasy).

Numerous participants dropped-out of the study. The differences between participants who completed the test and those who dropped-out were statistically analyzed.

Statistics

The statistical models were represented by mixed linear models in SPSS[®] 12.0 (Norusis, 2004). For all measures, the models included Device (Simulator, Vehicle), Motion

(Moving, Idling), and Group (Drop-Out, Complete) and the interactions between these factors as fixed effects. Participants within group was treated as a random effect. The covariance structure was variance components. Means and standard errors are reported.

RESULTS

Both experiments were marked by similarly high drop-out rates (Simulator Experiment: 12 of 16 participants; Vehicle Experiment: 13 of 16). Moreover, Figure 2 illustrates that for both of the experiments, the majority of the drop-outs occurred in the conditions excluded from the present study. Overall, the average drop-out time was 45.1 ± 10.8 and 26.9 ± 5.2 min in the Simulator and Vehicle Experiments respectively. Within only the conditions included in this study, the drop-outs averaged 34.1 ± 3.2 and 30.8 ± 3.0 min in the Simulator and Vehicle Experiments respectively. All but one drop-out in each condition reported that they dropped out due to feeling ill. Because of the drop-outs, fewer than the maximum number of participants performed the Idling ($n = 8$, Simulator, $n = 6$ Vehicle) and the Moving ($n = 8$ Simulator, $n = 6$ Simulator) conditions.

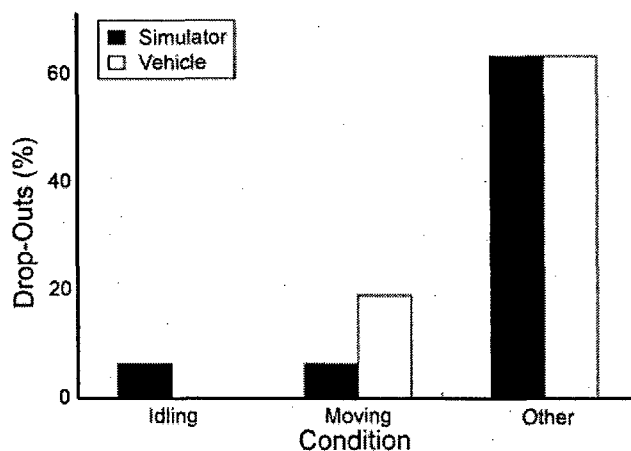


Figure 2. The percentage of drop-outs per condition. Drop-out percentages were calculated as ratios of the Drop-outs to the total number of participants. "Other" indicates the two conditions in each experiment not included in this analysis.

Driving Performance

Significant Device main effects ($p's < .05$) were found for Speed_{MAX}, Speed_{CC}, Error_{MIN}, and % Error. The speed and error results are consistent with a speed-accuracy trade off between experiments. Specifically, in the Vehicle Experiment participants drove faster but less accurately, than in the Simulator Experiment. Interactions ($p's < .05$) were observed for Error_{MIN} including Motion by Group and Device x Motion. The Motion x Group interaction indicates a similar pattern between the Drop-Out and Complete Groups for the Motion manipulation across Device (Figure 3). However, the Moving condition was associated with

greater errors in the Vehicle Experiment than in the Simulator Experiment (Figure 3).

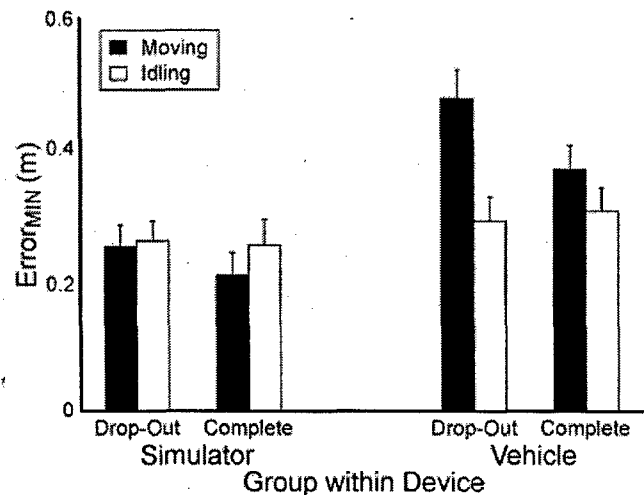


Figure 3. Motion x Group and Device x Motion interactions for Error_{MIN}. The third-order interaction was not significant.

Motion Sickness Ratings

Significant Motion main effects ($p's < .05$) were observed for the MSAQ Gastrointestinal, Peripheral, and Sopite-Related subscales. Figure 4, which shows data for the Gastrointestinal Subscale, illustrates the general finding across all three of these subscales of greater effects for Moving than for Idling in both Experiments. For the Peripheral subscale, a Motion x Group interaction ($p < .05$) was observed indicating the Moving condition only influenced the Drop-out group, and that occurred in both experiments (Figure 5).

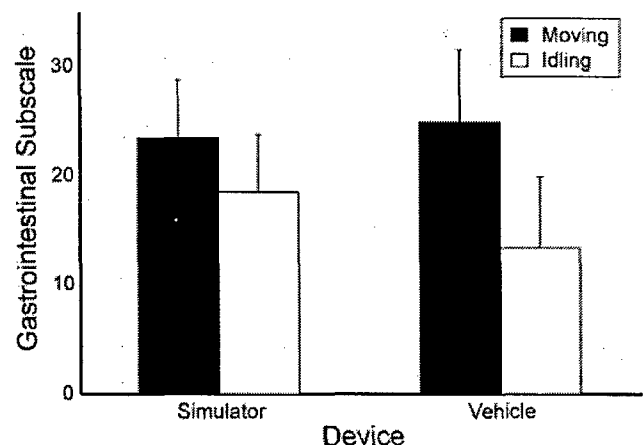


Figure 4. Motion x Device interaction for the Gastrointestinal subscale.

DISCUSSION

In this study, we assessed the validity of using a motion-base to simulate the physical motion of a HMMWV during an evaluation of human performance while on the move.

Overall, support was found for both the *absolute* and *relative* validity of using the simulator to examine issues related to motion sickness. Clear differences across conditions were observed in several motion sickness subscales. Most important, similar differences were observed for both the *scale* and the *pattern* of the results in the simulated and the actual motion environments.

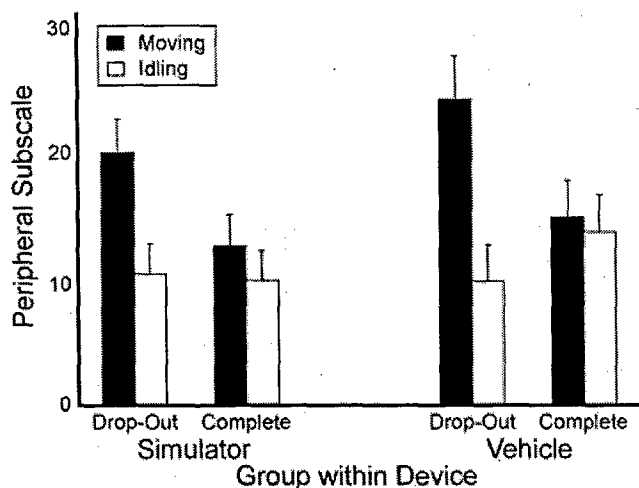


Figure 5. Motion x Device x Group interaction for the Peripheral Subscale.

The performance data did not lend clear support for RMS simulator validity. The higher speed and lower accuracies in the Vehicle Experiment suggest that participants drove with a different style in the two experiments. This may have resulted from differences in the additional two conditions in each experiment. That is, in those conditions in the Simulator Experiment, participants experienced feedback from the task into the physical motion. However, this did not occur in the Vehicle Experiment. Furthermore, support for simulator validity would have been difficult to find considering virtually no differences were observed in the driving metrics between the Moving and Idling conditions. Future efforts should focus on refining driving performance measures and address the validity of the RMS human performance measures in real situations.

CONCLUSIONS

Motion-base simulators can be used to examine future forces tasks such as command and control that *must* be performed on the move. Our results here suggest that simulators such as the RMS may be good for inducing specific types of behaviors observed in real-life behaviors. However, future work is needed using the validation approach discussed here to understand the extent and the limits to which motion-base studies are useful.

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